

DESCRIPTION

METHOD OF MEASURING OPTICAL FIBER DRAWING TENSION

5 TECHNICAL FIELD

The present invention relates to a method of manufacturing an optical fiber, and more specifically, to a method of accurately and stably measuring tension applied to an optical fiber when it is being drawn.

10

BACKGROUND ART

Generally, when an optical fiber is manufactured, an optical fiber preform is melted by heating from its lower end portion, to pull (draw) the melted and deformed
15 portion thereof into a linear shape. Also, the surface of the optical fiber that is obtained immediately after the drawing by heating, is coated with a thermosetting resin, a UV curing resin or the like. The manufacture of the optical fiber with such heating and pulling means is
20 generally referred to as "drawing".

In case of obtaining an optical fiber through drawing of an optical fiber preform, if tension applied to the optical fiber during drawing is not controlled, there occurs a change in the transmission characteristics,
25 particularly in transmission loss, of the optical fiber in

a longitudinal direction. Thus, it is required that the tension when the optical fiber preform is drawn be controlled so as to be a prescribed value. Specifically, there is a need to measure and control tension applied to the optical fiber being drawn.

In addition, in case of measuring the tension applied to the optical fiber, the optical fiber will be damaged when a contact type measuring device is used. Therefore, a non-contact type measuring device is generally used, to measure the tension applied to the optical fiber.

Here, explanation will be made of a method of measuring tension applied to an optical fiber being drawn. A general method of measuring tension applied to an optical fiber being drawn is a method utilizing oscillation of the optical fiber generated when drawing.

According to this method, target tension T is obtained by acquiring a fundamental oscillation frequency f from a peak of a measured oscillation waveform spectrum, and thereafter substituting the fundamental oscillation frequency f for the following equation (1).

Equation (1)

$$T=(2\cdot L\cdot f)^2\cdot\rho\cdot\alpha$$

In the equation (1) above, L represents a distance between an optical fiber preform and a coating die used

for forming a first coating layer on the optical fiber (first coating die). Further, ρ represents a linear density, and α represents a correction factor.

On the other hand, for enabling measurement of the tension T using the equation (1) above, it is required that the fundamental oscillation frequency f be obtained. As a conventional method, as shown in JP-A-62-137531 ("JP-A" means unexamined published Japanese patent application), there is known a method in which an oscillation waveform is subjected to the Fourier transform and a fundamental oscillation frequency is determined based on frequency components of the resulting oscillation waveform.

However, in the method disclosed in JP-A-62-137531, in a case where there are spectrum peaks other than that of the fundamental oscillation frequency, it becomes difficult to determine the fundamental oscillation frequency. In an actual case, there arise a peak of oscillation, which is obtained by multiplying the fundamental oscillation frequency by an integer, and a peak which does not correspond to the fundamental oscillation frequency multiplied by an integer. Therefore, it is required that influence caused by those peaks be removed.

Therefore, as shown in U.S. Patent No. 5,079,433, there is a method of finding a set of spectrum peaks that

are close to relation between the fundamental oscillation frequency and a double frequency, from among all of the spectrum peaks.

Further, as shown in JP-A-10-316446, there is a
5 method in which, when performing the first time peak frequency retrieval, the retrieval is conducted within a frequency range where it is expected that a peak frequency is included, for example, in a vicinity of a target value, to thereby perform subsequent peak frequency retrievals in
10 a state where a median value of the peak frequency retrieval is moved to the previously detected peak frequency.

However, in the technique described in U.S. Patent No. 5,079,433 and JP-A-10-316446, there is fear that error
15 measurement of the fundamental oscillation frequency arises in a case where a noise is a frequency that is close to the fundamental oscillation frequency of the optical fiber or that is close to the frequency obtained by multiplying the fundamental oscillation frequency by an
20 integer, or in a case where there is a noise peak within the peak retrieval range.

Therefore, in the conventional methods, there has been required means for accurately measuring the tension applied to the optical fiber being drawn, by precisely
25 recognizing the fundamental oscillation frequency of the

optical fiber regardless of noise generating conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic explanatory diagram showing an
5 example of an optical fiber drawing device, to which is
applied a method of measuring tension applied to an
optical fiber being drawn, which method is an embodiment
of the present invention.

Fig. 2 is a flow chart exemplifying respective steps
10 for obtaining tension applied to an optical fiber being
drawn, in accordance with an embodiment of the present
invention.

Fig. 3 is a waveform diagram showing an example of
an oscillation waveform of an optical fiber.

15 Fig. 4 is a waveform diagram showing a result of
subjecting the waveform diagram of Fig. 3 to spectrum
analysis.

Fig. 5 is a waveform diagram showing a result of
calculating autocorrelation of spectrum components shown
20 in the waveform diagram of Fig. 4 and thereafter smoothing
it.

DISCLOSURE OF THE INVENTION

The present invention is a method of measuring
25 tension applied to an optical fiber being drawn, which

method comprises: measuring oscillation of the optical fiber when drawing into the optical fiber; subjecting a waveform of the oscillation to frequency analysis to obtain spectrum components; determining a fundamental oscillation frequency of the optical fiber based on peak frequencies contained in the spectrum components; and converting the fundamental oscillation frequency into the tension applied to the optical fiber being drawn,

characterized in that the determination of the fundamental oscillation frequency of the optical fiber is performed through the steps comprising:

specifying, as a harmonic oscillation series group, a group of peak frequencies containing at least two peak frequencies, in which an interval between a frequency zero (0) and a first peak frequency, an interval between the first peak frequency and a second peak frequency, ..., and an interval between an (n-1)th peak frequency and an nth peak frequency (in which n is a natural number) are equal to each other, from among a plurality of peak frequencies contained in the spectrum components; and

determining the fundamental oscillation frequency of the optical fiber based on the respective peak frequencies contained in the specified harmonic oscillation series group.

Other and further features and advantages of the

invention will appear more fully from the following description, taken in connection with the accompanying drawings.

5 BEST MODE FOR CARRYING OUT THE INVENTION

According to the present invention, there are provided the following means:

(1) A method of measuring tension applied to an optical fiber being drawn, comprising: measuring
10 oscillation of the optical fiber when drawing into the optical fiber; subjecting a waveform of the oscillation to frequency analysis to obtain spectrum components; determining a fundamental oscillation frequency of the optical fiber based on peak frequencies contained in the
15 spectrum components; and converting the fundamental oscillation frequency into the tension applied to the optical fiber being drawn,

characterized in that the determination of the fundamental oscillation frequency of the optical fiber is
20 performed through the steps comprising:

specifying, as a harmonic oscillation series group, a group of peak frequencies containing at least two peak frequencies, in which an interval between a frequency zero (0) and a first peak frequency, an interval between
25 the first peak frequency and a second peak frequency, ...,

and an interval between an (n-1)th peak frequency and an nth peak frequency (in which n is a natural number) are equal to each other, from among a plurality of peak frequencies contained in the spectrum components; and

5 determining the fundamental oscillation frequency of the optical fiber based on the respective peak frequencies contained in the specified harmonic oscillation series group;

(2) The method of measuring tension applied to an
10 optical fiber being drawn according to the item (1), characterized in that, when specifying the harmonic oscillation series group, autocorrelation of the spectrum components is calculated, thereby the peak frequencies that are in the harmonic oscillation series relation at
15 equal intervals are emphasized; and

(3) The method of measuring tension applied to an optical fiber being drawn according to the item (2), characterized in that, when emphasizing the peak frequencies that are in the harmonic oscillation series
20 relation at equal intervals by calculating autocorrelation of the spectrum components, data obtained after the calculation of the autocorrelation are smoothed.

The inventors of the present invention have made extensive studies in view of the above points and obtained
25 the following findings as a result. That is:

When determining the fundamental oscillation frequency of the optical fiber based on the peak frequencies contained in the spectrum components of the oscillation waveform of the optical fiber, it is carried out first specifying, as the harmonic oscillation series group, the group of peak frequencies containing at least two peak frequencies, in which the interval between the frequency zero (0) and the first peak frequency, the interval between the first peak frequency and the second peak frequency, ..., and the interval between the (n-1)th peak frequency and the nth peak frequency (in which n is a natural number) are equal to each other, from among a plurality of peak frequencies contained in the spectrum components, thereby peak frequencies, which do not correspond to the harmonic oscillation series group and are not periodical, are judged to be noises and removed from the group of peak frequencies; and, subsequently, determining the fundamental oscillation frequency of the optical fiber based on the respective peak frequencies contained in the harmonic oscillation series group. According to the above, it becomes possible to accurately obtain the fundamental oscillation frequency of the optical fiber.

Further, when extracting the harmonic oscillation series group, by calculating autocorrelation of the

spectrum components, thereby emphasizing the peak frequencies that are in the harmonic oscillation series relation at equal intervals, the harmonic oscillation series group can be easily and certainly specified.

5 Furthermore, when calculating autocorrelation of the spectrum components, to emphasize the peak frequencies that are in the harmonic oscillation series relation at equal intervals, by smoothing data obtained after the calculation of the autocorrelation, the harmonic
10 oscillation series group can be more easily and certainly specified.

Hereinafter, an embodiment of the present invention will be described with reference to the drawings.

Fig. 1 is an explanatory diagram showing an example
15 of an optical fiber drawing device that can be used for the method of measuring tension applied to an optical fiber being drawn according to the present invention. In the drawing device shown as an example in Fig. 1, an optical fiber preform (source material) 2 inserted into a
20 heating furnace 1 is melted by heating from its lower end portion by a heater 3, and the resulting melted portion thereof is drawn, to thereby manufacture a secondary coated optical fiber 4c consecutively through a preparing process in the following order: the optical fiber preform
25 2 → an optical fiber 4a → a primary coated optical fiber

4b → the secondary coated optical fiber 4c.

In Fig. 1, the heating furnace 1 has a cylindrical carbon-made heater 3 built therein. A ring-shaped outer diameter gauge 5 is provided for measuring an outer
5 diameter of the optical fiber 4a immediately after being drawn and coming out of the heating furnace 1. A cooler 6 in an elongate cylindrical shape is provided for cooling the optical fiber 4a having passed through the outer diameter gauge 5. A non-contact type oscillation
10 detecting sensor 7 is provided for detecting oscillation of the optical fiber 4a, which has passed through the cooler 6 and is passing therethrough, and the sensor is composed of, for example, a laser displacement gauge. A first coating die 9 is provided for forming a primary
15 coating layer by coating a thermosetting resin or a UV curing resin on an outer peripheral surface of the optical fiber 4a passing therethrough. A first coat hardener 10 is provided for curing the coating resin coated on the primary coated optical fiber 4b passing therethrough. The
20 first coat hardener 10 to be used is, for example, of a heating type in a case where the coating resin is the thermosetting resin, and is of a UV-ray irradiation type in a case where the coating resin is the UV curing resin. A second coating die 11 and a second coat hardener 12 are
25 substantially the same as or similar to the first coating

die 9 and the first coat hardener 10 already described,
respectively. A turn sheave 13 is provided for changing
an advancing direction of the secondary coated optical
fiber 4c having passed through the second coat hardener 12
5 so as to direct the secondary coated optical fiber 4c to a
winder (not shown).

A system of tension measurement in the optical fiber
drawing device shown in Fig. 1 is constructed of the non-
contact type oscillation detecting sensor 7, a tensiometer
10 8 for calculating tension T of the optical fiber 4a based
on a signal inputted from the non-contact type oscillation
detecting sensor 7, and the like. These devices are
electrically connected with each other in an order of, for
example, the non-contact type oscillation detecting sensor
15 7 \rightarrow the first tensiometer 8.

In the device exemplified in Fig. 1, the tensiometer
8 is composed of a personal computer, a programmable
computer, or the like.

With the optical fiber drawing device shown in Fig.
20 1, the optical fiber 4a, the primary coated optical fiber
4b, the secondary coated optical fiber 4c and the like are
manufactured from the optical fiber preform 2 step-by-step
and consecutively as follows.

The optical fiber preform 2 that is inserted into
25 the heating furnace 1 at a substantially constant speed is

melted by heating from its lower end portion by the heater 3 in the furnace, and the melted portion is taken-out at a speed of, for example, 100 m to 1500 m per minute, thereby an extremely fine optical fiber 4a having a diameter of, 5 for example, 125 μm is obtained. The optical fiber 4a immediately after coming out of the heating furnace 1 is measured of its outer diameter by the outer diameter gauge 5 and is cooled inside the cooler 6.

The optical fiber 4a having passed through the 10 cooler 6 is detected of its oscillation by the non-contact type oscillation detecting sensor 7. Thereafter, the optical fiber 4a is coated with a resin by means of the first coating die 9 to become the primary coated optical fiber 4b, and the primary coating layer is cured by the 15 first coat hardener 10.

The primary coated optical fiber 4b having passed through the coat hardener 10 becomes the secondary coated optical fiber 4c through resin coating by the second coating die 11, and the secondary coating layer is cured 20 by the second coat hardener 12.

Further, the secondary coated optical fiber 4c having passed through the second coat hardener 12 is wound by the winder (not shown) via the turn sheave 13.

In the example described above with reference to Fig. 25 1, the non-contact type oscillation detecting sensor 7

arranged in a predetermined position detects the
oscillation of the optical fiber 4a, and the tensiometer 8
to which the oscillation detecting signal is inputted from
the non-contact type oscillation detecting sensor 7
5 calculates the tension T of the optical fiber 4a.

In the present invention, in a case where the
oscillation of the optical fiber is detected by the non-
contact type oscillation detecting sensor and the tension
applied to the optical fiber is obtained based on the
10 detected data with a tensiometer, the following Step S1 to
Step S5 shown in Fig. 2 are adopted as one specific
example.

Step S1: Setting of spectral analysis frequency
range

15 A spectral analysis frequency range is set.
Specifically, the spectral analysis frequency range is set
as an initial value of the tensiometer 8.

Step S2: Collecting of data

In the tensiometer 8, data of a line position are
20 collected, for example, for several tens of seconds from
the non-contact type oscillation detecting sensor 7 by
setting a sampling interval of several msec to several
tens msec. The data of a line position collected for that
several tens of seconds are then memorized.

25 Step S3: FFT operation

The line position data are subjected to operation using FFT (fast Fourier transform), to obtain Fourier components of discrete data.

Step S4: Calculation of autocorrelation

5 From among a plurality of peak frequencies contained in the spectrum components that are obtained as a result of the FFT operation in Step S3, a group of peak frequencies containing at least two peak frequencies, in which an interval between a frequency zero (0) and a first
10 peak frequency, an interval between the first peak frequency and a second peak frequency, ..., and an interval between an (n-1)th peak frequency and an nth peak frequency (in which n is a natural number) are equal to each other, is specified as a harmonic oscillation series
15 group.

When specifying the harmonic oscillation series group, it is preferable to calculate autocorrelation of the spectrum components to emphasize the peak frequencies that are in the harmonic oscillation series relation at
20 equal intervals so as to certainly specify the harmonic oscillation series group. Here, the term "emphasizing" means a procedure, in which peak frequencies, which do not correspond to the harmonic oscillation series group and are not periodical, are judged to be noises and removed
25 from the group of peak frequencies, and only the peak

frequencies that are in the harmonic oscillation series relation at equal intervals are allowed to remain.

When calculating the autocorrelation in Step S4, the following equation (2) can be used.

5 Equation (2)

$$\rho(k) = \frac{\sum_{i=1}^{n-k} x(i+k) \cdot x(i) - \bar{x}_0(k) \cdot \bar{x}_k(k)}{\sqrt{\left\{ \sum_{i=1}^{n-k} x^2(i) - \bar{x}_0^2(k) \right\} \left\{ \sum_{i=1}^{n-k} x^2(i+k) - \bar{x}_k^2(k) \right\}}}$$

in which $\bar{x}_0(k) = \frac{1}{n-k} \sum_{i=k+1}^n x(i)$

$$\bar{x}_k(k) = \frac{1}{n-k} \sum_{i=1}^{n-k} x(i)$$

Here, Fig. 3 shows an example of an oscillation
 10 waveform of an optical fiber, and Fig. 4 shows spectrum components obtained through the FFT operation of the oscillation waveform of Fig. 3.

Specifically, using the equation (2) above, n
 spectrum data indicated by the spectrum waveform diagram
 15 of Fig. 4 are read as discrete data with respect to a frequency axis. Next, autocorrelation $\rho(k)$ with respect to kth data $x(k)$ (in which k is an integer of from 1 to

n) that is arranged on the frequency axis of Fig. 4 is obtained using the equation (2) above. The number n of data is enough to be a number that corresponds to the number of frequencies exceeding the number of peak
5 frequencies to be detected.

Fig. 5 shows a result obtained from the calculation of the autocorrelation of the spectrum components shown in Fig. 4 in Step S4 above. It is preferable that data are smoothed after the calculation of the autocorrelation, and
10 thus Fig. 5 shows the data having been smoothed. Here, the term "smoothing" means removal of influence caused by noise components having small amplitude, and smoothing can be performed in a usual manner. Comparing Fig. 5 to Fig. 4, the peak frequencies in Fig. 4, which do not correspond
15 to the harmonic oscillation series group and are not periodical, are judged to be noises and removed from the spectrum components, so that peaks exist only in frequencies that correspond to the harmonic oscillation series group in Fig. 5.

20 Step S5: Calculation of tension

A fundamental oscillation frequency of the harmonic oscillation series group specified in Step S4 (a peak in the lowest frequency) is determined as the fundamental oscillation frequency f of the optical fiber, and the
25 value thereof is substituted for the equation (1), to

obtain the tension T of the optical fiber.

As a result of performing the steps shown in Fig. 2, the tension applied to the optical fiber being drawn is measured substantially accurately regardless of noise
5 conditions.

The embodiment of the present invention is not limited to the one described above, in which concrete examples of the respective steps are shown in Fig. 2, and the present invention can be freely modified within the
10 scope of the invention as described in the accompanied claims. For example, the number of peak frequencies of the harmonic oscillation series group specified in Step S4 may be any number as long as the number is two or more. Further, it is needless to mention that, in Step S5, a
15 change may be performed in which an average value of the peak frequency intervals of the harmonic oscillation series group specified in Step S4 is determined as the fundamental oscillation frequency f of the optical fiber.

According to the present invention, when determining
20 the fundamental oscillation frequency of the optical fiber based on the peak frequencies contained in the spectrum components of the waveform of the optical fiber, the group of at least two peak frequencies, which are contained in the spectrum components and are in the harmonic
25 oscillation series relation at equal intervals, is first

specified as the harmonic oscillation series group.
According to the above, the peak frequencies, which do not
correspond to the harmonic oscillation series group and
are not periodical, are judged to be noises and removed
5 from the group of peak frequencies. Next, the fundamental
oscillation frequency of the optical fiber is determined
based on the respective peak frequencies contained in the
harmonic oscillation series group. In this way, the
fundamental oscillation frequency of the optical fiber can
10 be accurately obtained.

Further, according to the present invention, when
extracting the harmonic oscillation series group, the
autocorrelation of the spectrum components is calculated
and the peak frequencies that are in the harmonic
15 oscillation series relation at equal intervals are
emphasized. According to the above, the harmonic
oscillation series group can be easily and certainly
specified. As a result, the tension applied to the
optical fiber being drawn can be more accurately measured.

20 Furthermore, according to the present invention,
when calculating the autocorrelation of the spectrum
components, to emphasize the peak frequencies that are in
the harmonic oscillation series relation at equal
intervals, the data after the calculation of the
25 autocorrelation are smoothed. According to the above, the

harmonic oscillation series group can be more easily and certainly specified.

INDUSTRIAL APPLICABILITY

5 According to the method of the present invention, it is possible to more accurately, easily and stably measure the tension applied to the optical fiber when it is being drawn, utilizing the oscillation waveform of the optical fiber. Therefore, the method of the invention is
10 preferable when applied as a method of stably manufacturing the optical fiber, by controlling the tension applied to the optical fiber being drawn and by reducing the change in the transmission characteristics of the resultant optical fiber in the longitudinal direction
15 thereof.

 Having described our invention as related to the present embodiments, it is our intention that the invention not be limited by any of the details of the
20 description, unless otherwise specified, but rather be construed broadly within its spirit and scope as set out in the accompanying claims.